Converging sources of evidence and theory integration in working memory

Converging sources of evidence and theory integration in working memory:

A commentary on Morey, Rhodes, and Cowan (2019)

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Abstract

Morey et al. (2019) offer a critique of the dominance of the multiple component framework of working memory in the interpretation of patterns of impairment and sparing in individuals with focal brain damage associated with specific impairments of immediate, serial-ordered verbal recall. They argue that the lack of pure cases of verbal short-term memory impairments, that recognition performance is higher than recall in such patients, that digits are remembered better than other verbal material, and that problems with replicability in patient studies undermine this traditional theoretical interpretation of the impairments from which these patients suffer. They further speculate that an alternative theoretical framework for working memory, incorporating embedded processes and perception-action links offers a more plausible account of the data from these patients. This commentary points to a range of errors and misconceptions in the arguments presented, notably that such patients are not as rare as suggested, that their recognition is actually no better than their recall, that digits offer substantial advantages for memory, and that results have been shown to be replicable between and within individuals. It is proposed that attempts to integrate more recent theoretical developments in working memory with those shown previously to be highly successful in accounting for impairments in these patients, and for generating hypotheses and accounts across a wide range of contexts may be a more fruitful approach to advancing understanding of cognition in the healthy and damaged brain.

Debates in science offer fora to challenge assumptions, to consider alternative interpretations of data, and can be a driver for progress in understanding based on theory development. Debates can be less useful and can self perpetuate without a possible resolution if the protagonists are essentially asking quite different research questions, are effectively seeking different levels of explanation, are using different labels to refer to what are essentially the same concepts, or have as their primary goal to argue for their respective theories rather than a shared goal of advancing understanding and theory integration. The issue then arises as to what criteria might be set for resolving a debate by considering the arguments, assumptions, and research goals on both (or all sides). One approach is to set up empirical tests that attempt to falsify a theory (Popper, 1959). Although there are reports of contrasting evidence that create specific challenges for one or another theory, I am not aware of successful attempts to falsify any of the multitude of theories of working memory across five decades of research on the topic. Moreover, attempts to directly contrast theories using Popperian logic can result in data that neither completely falsify nor completely support the theories being compared (e.g. Doherty et al., 2018; Rhodes et al., 2018). This might stem from the fact that most theories of working memory are conceptual theoretical frameworks that make qualititative rather than quantitative predictions. Such an approach allows for use of a theory in a wide variety of contexts, and with a wide range of data, but suggests that a Popperian falsification is not ideal for advancing knowledge in our discipline. More formal theories, for example using computational modelling, tend to focus on specific tasks or a limited range of tasks such as immediate, verbal serial ordered recall (e.g. Hurlstone, Hitch, & Baddeley, 2013), limiting their generality, and limiting the understanding of the cognition that might support task performance. An alternative is to adopt a more utilitarian approach (e.g. Lakatos, 1968; see recent discussion in Baddeley, Hitch, & Allen, 2018), and consider how useful a theory is in providing an account for data patterns from different sources, using different methods and participant samples for generating new hypotheses, all with the ultimate goal of helping us understand human cognition. If one side of the debate adopts a Popperian approach, and the other is more utilitarian, then the debate is unlikely ever to be resolved or help advance understanding. Debates can also self-perpetuate with no end in sight because of subtle but crucial differences in experimental materials, methods, procedures, participant samples, or variation in how different participants perform the same task (for a recent discussion see Logie, 2018).

Morey, Rhodes, & Cowan (2019) discuss one stimulus for debate regarding working memory, namely the observations from single case studies of individuals with focal brain damage who have been reported as having impairments in their immediate serial ordered recall of aurally presented verbal sequences, but largely intact visual memory, language abilities, perceptual and executive functions, and long-term memory function including learning. Many of the studies of these, and other patients with focal brain damage and specific impairments have been conducted over the last 50 years within the context of the

multiple component theoretical framework for working memory (e.g. Baddeley, 1986; 2012; Baddeley & Hitch, 1974; Baddeley, Hitch, & Allen, 2019, in press; Baddeley and Logie, 1999; Della Sala & Logie, 1993; Hanley & Young, 2019, in press; Hanley, Young, & Pearson, 1991; Logie & Della Sala, 2005; Vallar & Shallice, 1990). The multiple component approach has developed from converging sources of evidence, adopting the more utilitarian approach described above. That is, how useful is this approach in understanding cognition in a wide range of contexts and with a wide range of different methodologies both in the laboratory and in applied settings? The multiple component approach has been found to be particularly useful in numerous different contexts, including healthy early age development (e.g. Gathercole & Baddeley, 1989; Hitch, Woodin, & Baker, 1989; Logie & Pearson, 1997), healthy adult ageing (e.g. Johnson, Logie, & Brockmole, 2010; Park et al, 2002), brain imaging (e.g. Paulesu et al., 2017; Logie, Venneri, Della Sala, Redpath, & Marshall, 2003; Nijboer, Borst, van Rijn, & Taatgen, 2014), developmental learning disorders (e.g. Gathercole et al., 2016), hyperbaric stress (e.g. Logie & Baddeley, 1985), acquisition of complex skills (e.g. Logie, Baddeley, Mane, Donchin & Sheptak, 1989), mental arithmetic (e.g. Hitch, 1978; Logie, Gilhooly, & Wynn, 1994), music (e.g. Williamson, Baddeley, & Hitch, 2010), cognitive effects of parasitic disease (Jukes et al., 2002), and of Alzheimer's disease (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Logie, Cocchini, Della Sala, & Baddeley; Logie, Parra, & Della Sala, 2015; MacPherson, Della Sala, Logie, & Willcock, 2007; Parra et al., 2009a), in addition to a very large number of studies of healthy adults (for a recent review and compilation of many of these studies see Baddeley, 2018). This approach has also been successful in providing accounts for studies of single cases with visual short-term memory deficits (De Renzi & Nichelli, 1975; Hanley & Young, 2019 in press; Hanley, Young, & Pearson, 1991; Parra, Della Sala, Logie, & Abrahams, 2009b; Warrington & Rabin, 1971; for a review see Logie & Della Sala, 2005), and the case studies of patients with severely impaired immediate oral serial recall of aurally presented verbal lists (e.g. Della Sala & Logie, 1993; Tree & Playfoot, 2019; Vallar, 2019; Vallar & Shallice, 1990). A small selection of the last kinds of studies are the target for the Morey et al. (2019) critique. In sum, the strength of the multiple component approach lies in its utility in generating hypotheses and accounting for a very broad range of types and sources of data that converge to support the core theoretical framework, as well as in its success in areas of application.

The General Critique

Morey et al. (2019) argue that the specific cases of verbal short-term memory deficits have been presented as a 'smoking gun', presumably suggesting that these cases are argued to be sources of compelling evidence for the multiple component framework, but are inconsistent with alternative theoretical frameworks. As noted above, there are many sources of such evidence, not just in this specific area of cognitive neuropsychology. However, the neuropsychological evidence from single case studies is most frequently seen as a source of evidence that is inconvenient for alternative theoretical frameworks. One very common approach to inconvenient evidence is to deny or ignore it, "both knowing and

not knowing" (Bellow, 1996; Fahey, 2013; Gore, 2006), or view it as of low value or questionable validity, and so choose not to consider its theoretical implications (e.g. Oberauer et al., 2018). Therefore, at first glance, the attempt by Morey et al. (2019) to consider the neuropsychological evidence critically and in some depth is welcome, as would be an attempt to try to integrate alternative theories with the theoretical framework that has been so successful in accounting for these data. Unfortunately, there are several errors, misconceptions and weaknesses in the arguments presented, some of which I highlight in this commentary. This was also the case for a similar argument directed at studies of specific visual short-term memory deficits (Morey, 2018a) which has been shown to include a number of factual errors as well as misconceptions (Hanley & Young, 2019). Morey (2018b) acknowledged these errors but curiously denied that the corrected errors undermined her argument that there is a lack of evidence for selective visual-spatial short-term memory deficits.

Like the Morey (2018a) critique of visual short-term memory deficits, the general theme of the Morey et al. (2019) critique of auditory-verbal short-term memory deficits is not to seek integration with the existing successful theoretical framework to enhance understanding. Instead, as indicated by the article title, the aim is to speculate that a more insightful interpretation might emerge from reframing the neuropsychological evidence within a domain-general theory. Specifically, the proposal is to develop a combination of two different and currently separate theories of working memory, comprising respectively activated long-term memory with a limited capacity focus of attention, collectively known as 'embedded processes' (Cowan, 1999; 2005; Cowan, Saults, & Blume, 2014), and direct links between perception and action (e.g. Jones, Hughes, & Macken, 2006; see Kinsbourne, 1972 for an earlier similar argument). The embedded processes approach is supported by a substantial body of evidence from studies of healthy adults and children, as well as some neuroimaging evidence, but has hitherto less commonly been considered in the context of neuropsychology. There are suggestions that the differences between Cowan's approach and the multiple component approach might be more a question of terminology, and more apparent than real (Baddeley et al., 2018; Cowan & Chen, 2008; Logie, 2011; Logie & Cowan, 2015). So some attempt to integrate these approaches and apply them to neuropsychological evidence could be useful, although that is not what Morey et al. propose. The perception-action approach is supported by a more limited body of evidence and within a limited range of methodologies, primarily with healthy adults, so its generalisability and utility are not clear, and it requires considerably more development and evidence from a range of methodologies to demonstrate that it offers a convincing alternative to established theories or any added value for cognitive neuropsychology.

The rationale for the Morey et al. (2019) critique, and the colloquial reference to a 'smoking gun' appears to stem from the view that the neuropsychological evidence acts as a hindrance to alternative theoretical developments. This seems a curious view. If a theoretical framework is successful in accounting for a wide range of data, and some of

those data offer a significant challenge to alternative theoretical perspectives, then it seems somewhat unusual in science to suggest that the successful theory should be abandoned in favour of the alternative. Were progress in theoretical understanding of neuropsychological evidence somehow hampered by the use of the multiple component framework, then there would be little evidence of advance in understanding of the impairments suffered by the individuals concerned. There would also be a complete lack of advancement in clinical applications that benefit diagnosis, management or therapeutic interventions that arise from the application of that theoretical framework. However, there have been considerable advances over the last 50 years in theoretical understanding of selective cognitive impairments in individuals with focal brain damage, as well as clinical applications arising from the use of the multiple component framework in neuropsychology. These advances suggest that the multiple component approach has been highly beneficial. For example, it is much more helpful to a brain damaged individual, and to the people caring for her/him to know that they have difficulty remembering a sequence of words and numbers, but have little difficulty remembering what things looks like or where they are, in planning and problem solving, in learning, or remembering what they did yesterday, than it is to suggest that they have a general deficit in their focus of attention or a general cognitive impairment (for a related discussion see Logie et al., 2015). It is not clear that the alternative framework proposed by Morey et al. would have led to the clinical benefits that derive from identifying what is impaired and what is not impaired in these individuals.

Of course, those who feel that the multiple component framework continues to be useful have to address, in other fora for discussion, findings from studies of healthy adults that are apparently inconsistent with its main assumptions. Recent studies by Doherty et al. (2018), and Rhodes et al. (2018) have attempted to do precisely that, and have suggested that attempts to integrate theoretical concepts are likely to be more successful and more useful than attempting to test whether one theory is correct and others are not. However, it is interesting that Morey et al. do not claim that the neuropsychological evidence from verbal short-term memory patients is inconsistent with the multiple component framework. Their argument is that those data might also be interpreted in the context of an alternative framework, but it is not clear how the attempt to do so will offer any genuine advance in understanding, or offer the clinical applications that have arisen from the original interpretation. In addition to its broad utility, the multiple component approach has long offered a synergy between theory and application, providing an understanding of cognitive impairments for clinical purposes, while the study of such impairments has helped develop the theory (for discussions see Della Sala & Logie, 1993; Logie et al., 2015).

Case Studies of Verbal Short-Term Memory Impairment

The focus in the Morey et al. (2019) critique is the range of reports of single case studies of brain damaged individuals who typically can recall just one or two items from a longer sequence of words, letters or digits that are presented aurally. This contrasts with

immediate serial-ordered recall of six or more items in most healthy adults. The single cases typically can recall more items with visual presentation and show visual errors in their recall, suggesting the use of a visual code supporting retention (e.g. Basso, Spinnler, Vallar, & Zanobio, 1982; Shallice and Warrington, 1970; Tree & Playfoot, 2019; Warrington & Shallice, 1969; 1972). Morey et al. claim that typically recognition memory is substantially better than is immediate serial oral recall in these patients, and that findings are difficult to replicate in other patients or with the same patient on different occasions. There is also reference to compensation strategies adopted by patients to circumvent their impairment as 'hacking' the task. This last comment appears to align cognitive strategies with illegal access to computer networks, to the use of an axe for felling a tree, to a pejorative term for a writer who is paid to write low-quality articles, or to manipulate data collection to achieve statistical significance. So, the use of this term does not seem an appropriate characterisation of alternative strategies that have been shown to support task performance, and that have been studied extensively in brain damaged individuals as well as in healthy participants (e.g. Baltes & Baltes, 1990; Burgess & Shallice, 1996; Fazio, Dewolf & Siegler, 2016; Logie, Della Sala, Laiacona, Chalmers, & Wynn, 1996*;* Morrison, Rosenbaum, Fair, & Chein, 2016; Park & Reuter-Lorenz, 2009; Vallar & Baddeley, 1984). I address the claimed contrast between recognition and recall later in this commentary, and first address the concern about replicability in cognitive neuropsychology.

Morey et al. claim that these cases are relatively rare in the research literature, and that the patients typically have additional cognitive problems, so are not 'pure' cases of verbal short-term memory impairment. However, rather more cases have been reported than the authors consider. For example, Shallice & Vallar (1990) review 14 such cases, and Vallar and Papagno (2002) review a further five cases. Shallice and Papagno (in press) present an updated review of a total of 20 cases, and note that detection of a specific auditory-verbal short-term memory impairment would not necessarily be part of the routine clinical assessment of all patients presenting with a brain lesion. So just how frequently such a specific impairment arises is not known, and those patients who have been studied in considerable depth may well be representative of many more individuals with similar characteristics whose impairments have been less extensively studied. That is, such patients might not be as rare among the population of patients with left hemisphere damage as Morey et al. suggest.

Although the patients considered by Morey et al. varied in terms of additional cognitive problems, what was common to them all was an impairment in immediate verbal serial ordered recall following auditory presentation, with intact long-term memory function. These reports of multiple, in-depth single case studies rather than group studies of patients reflect a standard procedure in cognitive neuropsychology since Caramazza (1986, Caramazza & McCloskey, 1988; for a recent review see Shallice, 2019) argued that averaging performance patterns from groups of patients can be misleading, given the heterogeneity of their lesions and patterns of impairment. Therefore, the common practice in

neuropsychology of studying multiple single cases serves to demonstrate the replicability of findings across different individuals, and weakens Morey et al.'s concerns on this issue. Moreover, demonstrating the same set of impairments across multiple individuals despite variation among them in any additional cognitive impairments offers a counterargument to the concern that no one case shows a specific (or 'pure') deficit in the absence of other cognitive difficulties. That is, as long as the evidence is accumulated across multiple single cases, the fact that no one single case shows a pure impairment does not matter for the purposes of interpreting the patterns of impairment and sparing that are common to them all. The accumulation of evidence for a common pattern of performance across multiple single cases might be seen as analogous to the widespread practice in experimental studies of groups of healthy individuals in which the focus is on a common pattern of performance across participants for the experimental variables of interest. However, typically in such studies, the aggregate data across all participants is assumed to reflect the performance of each individual participant. Typically, variations in performance patterns across individuals are treated as statistical noise, and data from individual participants that are dramatically different from the group pattern often are excluded from analyses. However, participants may vary in how they perform the task, and several studies have demonstrated that there can be substantial subgroups who do not show the aggregate pattern, despite the overall pattern exceeding the threshold for statistical significance (e.g. Logie et al., 1996; Morrison et al., 2016). However, nearly all such studies focus on aggregate data from the group rather than considering whether all individual participants show the same pattern or whether they all use the same strategy for generating task performance. Recently, Logie (2018) argued that the use of aggregate data across healthy individuals in cognitive experiments might lead to misleading conclusions, and also to some failures to replicate because of heterogeneity in how participants perform experimental tasks. So, studies with healthy participants might consider the multiple single case approach used in neuropsychology for some research questions regarding healthy cognition.

Fewer new cases of verbal short-term memory impairment have been reported over the last 20 years or so largely because the issue was considered well established and closed on the basis of over three decades of research between the late 1960s (e.g. Luria, Sokolov, & Klimkowski, 1967; Warrington & Shallice, 1969) through to the late 1990s (e.g. Vallar, Di Betta, & Silveri, 1997). Tree and Playfoot (2019) have reported one very recent case, and have drawn similar conclusions to the previous case studies, that their patient CT has a specific impairment of links between temporary auditory-verbal input and output memory buffers, and intact ability to retain the orthographic representations of visually presented words. In a recent review, Shallice and Papagno (in press) present clear, and well supported arguments for a dissociation between an impaired auditory-verbal and an intact visual short-term memory across the patients that they identify. As is also clear from the Shallice and Papagno review, the general approach in all of these studies was to carry out extensive cognitive assessments using a wide range of both standardised and theoretically motivated

tests, and on multiple occasions, sometimes over periods of several years. So, these studies are much more extensive than is typical for studying healthy individuals in order to have a complete picture of the pattern of impairment and sparing in each patient.

The issue of replicability can also be addressed by considering multiple testing sessions over an extended time scale for the same patient. For example, among well known cases of auditory-verbal short-term memory impairment, single case PV was first described by Basso et al. (1982), with follow up reports by, for example, Vallar and Baddeley (1984), Vallar and Papagno (1986), and Baddeley, Papagno and Vallar (1988), and in a recent update and review of the case by Vallar (2019). Fortunately, PV's pattern of impairments and sparing was fairly stable over the period of ten years during which most of her assessment was undertaken. Patient KF was also tested on multiple occasions (e.g. Shallice & Warrington, 1970; 1974; Warrington and Shallice, 1969; 1972) with a consistent pattern observed on each test session. So this should address any concerns that results could not replicate with repeated testing on the same patients. For some other patients, whose cognition deteriorates over time as a result of a neurodegenerative disease (e.g. Garrard, Maloney, Hodges, & Patterson, 2005) or recovers over time as a result of neural plasticity or neurorehabilitation (e.g. Wilson, 1987), consistency on retest is more difficult to demonstrate. In those cases, using the multiple single case approach is helpful to understand the nature of impairments at different stages of their deterioration or recovery. The primary motivation for the studies of single cases with stable impairments of immediate serial ordered verbal recall was to characterize what was impaired relative to what might be expected in a healthy adult of a similar age and with a similar level of education.

The patterns of impairment and sparing from the multiple studies of KF, PV and of other, similar patients then presented an opportunity to evaluate the one theory of working memory that was prevalent, and sufficiently well developed at the time, namely the phonological loop concept as part of a multiple component working memory system (Baddeley, 1983; Baddeley & Hitch, 1974; Baddeley, Lewis & Vallar, 1984). This offered a synergy in that it allowed a means to test predictions regarding the cognitive sequellae of focal brain damage from a theory derived from studies of healthy adults, thereby helping to develop the theory, and offered a means to understand the nature of the cognitive deficits from which these patients suffered. In the cases of both KF and PV, the conclusion was that there was damage to the system that could retain aurally presented verbal sequences. This was readily explained by assuming an impairment in the phonological store that was (and is - Baddeley et al., 2018) thought, in healthy adults, to hold short sequences of phonologically coded verbal items in serial order. However, language abilities were intact in both patients as was their ability to encode and recall events in their lives. A number of alternative interpretations proposed at the time (e.g. Kinsbourne, 1972; Strub & Gardner, 1974; Tzortzis & Albert, 1974) were shown by Shallice and Warrington (1977) to be rather more consistent with the concept of an impaired phonological input buffer than was initially apparent. This

all pointed to the concept of a domain-specific, and limited capacity temporary memory for a sequence of phonologically based representations.

In order to understand the impairments for KF, PV, and similar patients, the theory started with the finding from healthy participants that when a verbal list is presented visually, there is a tendency for errors in immediate ordered serial recall to be based on the phonology of the words rather than their visual appearance (Conrad, 1964). Overall performance drops when the task is accompanied by participants repeating an irrelevant word aloud, known as articulatory suppression, and the effect is larger for auditory presentation than with visual presentation (Baddeley et al., 1984; Murray, 1965). In addition, there are few, if any phonologically based errors for visually presented words with articulatory suppression. Therefore, articulatory suppression is widely interpreted as disrupting the translation of the orthographic form of visually presented words into a phonological form for temporary memory prior to recall. Healthy individuals are then thought to have available a temporary representation of the words based on other characteristics such as their visual appearance or their meaning (e.g. Lin, Chen, Lai, & Wu, 2015; Logie, Della Sala, Wynn, & Baddeley, 2000; Logie, Saito, Morita, Varma, & Norris, 2016; Saito, Logie, Morita, & Law, 2008; Tree, Longmore, Majerus, & Evans, 2011). In the case of PV, and for a previous case with similar impairments, KF (Warrington & Shallice; 1972), as well as the more recent case of CT (Tree & Playfoot, 2019), when words were presented visually, immediate serial ordered recall was better than with auditory presentation. Notably, with visual presentation, PV and similar patients recalled about the same number of items (3-4) as do healthy participants who are performing articulatory suppression. Both healthy controls with articulatory suppression and patients (without articulatory suppression) show visual errors under these conditions. In other words, with visual presentation, the patients appear to be performing like healthy participants whose ability to translate the items into a phonological code is impaired by articulatory suppression. However, the patients' ability to retain aurally presented sequences is well below that found for healthy participants, even when the latter are performing articulatory suppression. That is, the patients have an intact visual short-term memory for the orthographic representations of visually presented words, but unlike healthy individuals, they cannot supplement their performance by also using a phonologically based temporary memory that is impaired. That is, the latter is damaged in the patients, the former is not, highlighting a distinction between auditory-verbal STM and visual STM, both of which are available to support memory span in healthy participants unless the former is disrupted by articulatory suppression.

Hanley and Young (2019; Hanley, Young, & Pearson, 1991) make the converse case for a patient ELD with a visual-spatial short-term memory deficit in the absence of an impairment of immediate serial ordered verbal recall. Studies of additional single case studies of visual short-term memory impairments are reviewed in Logie and Della Sala (2005). It is also worth noting that Morey (Morey & Mall, 2012; Morey, & Miron, 2016) has argued that retention of visual information is typically more vulnerable to disruption from a concurrent cognitively

demanding task than is retention of auditory-verbal information (for similar arguments see Phillips and Christie, 1977; Salway & Logie, 1995). That is, in terms of a theory of limited capacity attention, visual temporary memory is much more attentionally demanding than is verbal short-term memory. If it is the case that the patients have a general memory deficit linked with an impairment in the focus of attention, why is it that verbal short-term memory is impaired in these patients but visual short-term memory is largely intact? Surely retention of visual information should be more vulnerable to the impact of brain damage in a domain-general attentional system. The opposite is the case for PV, KF and similar patients. For similar reasons, it is then difficult to argue that patients who show the opposite pattern, such as ELD, do so because of a general rather than a specific cognitive impairment. This is a case where the concept of a shared, limited capacity attentional resource faces substantial challenges when used to interpret the range of specific deficits found in patients with focal brain damage.

The Case Studies Considered by Morey et al.

As the basis for their critique Morey et al. focus on a limited selection of the data from seven cases, patients JB, KF, WH (Warrington, Logue, and Pratt, 1971; Warrington and Shallice, 1969; 1972), patient PV (Basso et al., 1982), and three patients reported by Tzortzis and Albert (1974). Morey et al. (2019- Figure 2) note that patients JB, KF, PV, and WH, can recall more numbers than letters in a sequence, and argue that this is problematic for suggesting that there is an impairment of an auditory-verbal temporary memory system. This issue has already been addressed and dismissed by Vallar & Papagno (2002). The argument makes the strong assumption that memory in immediate serial ordered recall is entirely dependent on the system thought to be damaged in these patients. It has long been established for healthy adults, that immediate serial recall of words is very much better than is recall of non-word sequences (e.g. Hulme, Maughan, & Brown, 1991), and that there are long-term memory as well as short-term memory contributions to immediate serial verbal recall (Hulme, Roodenrys, Brown, & Mercer, 1995). Numbers are very much more frequent in everyday use than are random sequences of letters, are much less phonologically confusable, and they are drawn from a much smaller set. Given that a characteristic of these patients is that they have intact access to long-term memory, it is then hardly surprising that they show the same advantage for numbers that is found in healthy adults. The example of PV is particularly apposite, because she ran a small shop and had a lifetime of undertaking mental calculations with numbers as prices of goods in the shop. So random sequences of digits would have had some meaning for her as prices, and at the time she was tested, the Italian currency involved dealing with very large numbers for thousands of Lire. She had very much less experience of dealing with random sequences of letters. So, the superior ability with numbers for PV and similar patients is not a particular puzzle. It simply reflects learned expertise with number sequences. Another aspect of PV's performance was that she could learn new associations between pairs of Italian words, but could not learn Italian-Russian word pairs. That is, she could learn using a familiar phonology, but had great difficulty

learning paired-associates that involved an unfamiliar phonology (Baddeley, Papagno, & Vallar, 1988). In other words, she could draw on her intact long-term memory for Italian phonology to support learning, but she had difficulty with novel, unfamilar material that would rely on her impaired ability to retain a novel, phonological sequence in the correct order in memory long enough to reproduce it. This is consistent with a specific verbal short-term memory system that is impaired.

Recognition versus Recall

Another major argument from Morey et al. (2019- Figure 1) is that recognition in KF and the three patients reported by Tzortzis & Albert (1974) is much better than recall. First, it is striking that Morey et al. used a different combination of patients to make this case than they do for the contrast in Figure 2 regarding recall of digits and letters. Data on recognition and recall for patients JB, PV, and WH are not considered in Figure 1, and it is clear in the original reports (Basso et al., 1982; Warrington et al., 1971), that none of those patients showed better recognition than recall performance. For the patients that are considered in Figure 1, Morey et al. do not allow for the dramatically different chance levels between the different methods for testing recognition and for testing recall. Both Tzortzis and Albert (1974), and Warrington and Shallice (1969) tested recognition by presenting the patients with two sequential strings of numbers, letters, or words. On half of the trials, one item was different between the pair of strings, and the patient had to decide if the strings were the same or different. That is chance performance was 50%, regardless of the length of the string. Moreover, the patients would only have to remember two of the items to correctly detect a change for all trials with two items, for two thirds of the trials with three item sequences, and on half of the trials for a four item sequence. So, patients with a memory span of two items could easily generate the performance levels on these tasks for recognition shown by Morey et al. in Figure 1. Also, it is notable, that patient CS1, whose span for serial recall was around one item, scored at 50% chance level on recognition for a four item list, so was completely guessing. The higher scores for recognition arise because of the nature of, and different chance levels for the tasks, not because recognition performance was better than recall. In other words, none of the patients showed convincing evidence for better recognition than recall performance. Therefore, this claim by Morey et al. is very misleading, and the view that this undermines the argument for a specific verbal short-term memory impairment in these patients is not supported by the evidence on recall and recognition.

Impairments of Long-Term Memory and Neuroanatomy

In addition to the importance of considering the common patterns across multiple single cases of verbal short-term memory deficits, an additional key argument should be to consider individuals with impairments of long-term memory in the absence of short-term memory impairments. That is, studies of patients with verbal short-term memory deficits present only part of the picture. In the interests of keeping this commentary focused on the

main topic of the Morey et al. (2019) critique, and to keep this commentary to a reasonable length, I will discuss these cases only briefly before concluding.

Patients with verbal short-term memory impairments typically have intact hippocampi, and lesions are in temporo-parietal areas of the left hemisphere, notably the angular and supramarginal gyri (e.g. Vallar, 2019). Individuals with focal lesions in the hippocampi typically have completely normal ability to repeat back sequences of verbal items (e.g. Squire, 2017), but after a delay are unable to remember other information they are given, what they have done, and seem unable to learn to find their way around a new environment, such as a hospital. The most famous of these individuals, HM (e.g. Milner, Corkin, & Teuber, 1968) suffered damage to both hippocampi from neurosurgery intended to control his severe epilepsy. Although the epilepsy was much reduced, he was left with a dense amnesia that resulted in an inability to recall information or events after a delay, yet could hold conversations, and had normal working memory function. Numerous other similar cases have been reported, typically associated with hippocampal damage, and although there is variation across these patients in other cognitive deficits that they exhibit, the contrast of intact working memory but severely impaired learning and long-term retention is common (e.g. Baddeley, Jarrold, & Vargha-Khadem, 2011; Kapur & Logie, 2003; Squire, 2017). The contrast between these hippocampal patients and the verbal short-term memory patients such as KF and PV is striking, and most readily explained by assuming that this reflects a contrast in healthy cognition between short-term verbal memory and long-term learning, each associated with different brain networks that are damaged selectively in different patients. Alternative accounts may be possible, but additional assumptions would be required for most alternative theories. Crucially, this further highlights the importance of considering the broader range of evidence from patients with contrasting as well as with similar patterns of neuropsychological impairment and sparing rather than focusing on a limited number or range of patients.

Conclusions

Morey et al. (2019) were motivated by a concern that interpretations of patients with impairments of immediate serial ordered verbal recall are often viewed as a source of definitive support for the multiple component theoretical framework for working memory, and difficult to explain within the context of alternative, domain-general theories, such as embedded processes. The latter has been successful in accounting for patterns of performance in healthy children and young adults, as well as some neuroimaging data. I have argued that there are several errors and misconceptions in their target article regarding the tasks, results, and details of the methodology in studies of these patients. These include a lack of consideration of the use of multiple single cases rather than focusing on a small number of single cases, the intensive testing involved to demonstrate replicability and fully understand the pattern of sparing and impairment in each patient, and the possibility that both multiple aspects of cognition, and multiple cognitive strategies

contribute to task performance both in healthy individuals and patients. Moreover, the key argument presented by Morey regarding the contrast between recognition and recall arises as an artefact of differences in chance levels between the recall and recognition tasks, and there is no evidence that recognition and recall differ in the performance of the patients. Likewise , superior performance with digits compared with other verbal materials can readily be explained by familiarity with digits and the limited stimulus set that is not prone to effects of phonological similarity. So, this too offers no support to the critique of conclusions that have developed over more than five decades of careful and detailed research in cognitive neuropsychology. The current commentary only scratches the surface of a very substantial literature (see e.g. MacPherson & Della Sala, 2019) on very many more patients with contrasting patterns of impairment. Retrospective re-interpretation of this very large volume of evidence is very challenging, particularly when using theoretical frameworks that were not available at the time to influence the testing protocol for these patients.

Through future collaborations between experimental cognitive psychologists who disagree, and between cognitive psychologists and cognitive neuropsychologists, there are multiple interesting and new questions that could be addressed in empirical studies of patients by considering more recent theoretical developments. Such an approach would provide a very much more substantial foundation to offer added value to the interpretation of the large volume of previous studies than does the retrospective approach in this target article. As noted in the opening paragraph, theoretical debates can sometimes be fuelled by errors and misconceptions, by different assumptions about the status of evidence, by different criteria for evaluating theories, and by use of different labels for what are potentially very similar concepts. With new, and different studies of individual cases, and with a more open minded approach to theory utility and theory integration rather than falsification and replacement of theory that has been shown to be successful, the general approach of critical re-evaluation has future potential to make substantial and important contributions to understanding of human cognition in the healthy and damaged brain.

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